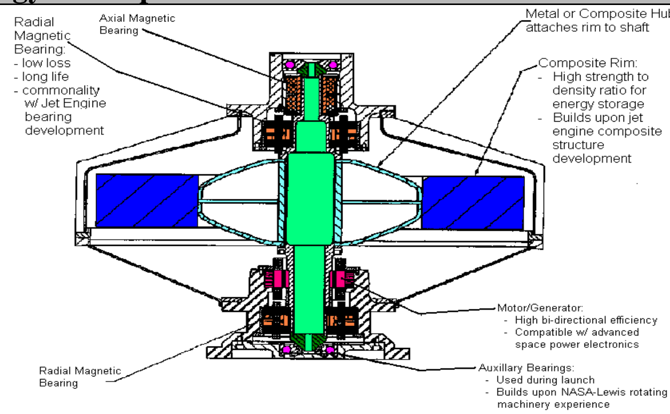
Advanced Energy Storage

Technology Description

The U.S. electric utility industry has been facing new challenges with deregulation and limitations on installing new transmission and distribution equipment. Advanced storage technologies under active development, in addition to advanced batteries, include processes that are mechanical (flywheels), purely electrical (supercapacitors, super conducting magnetic storage), and compressed-air energy storage. These advanced energy-storage solutions will help achieve more reliable and low-cost electricity storage.



Flywheel Cutaway

System Concepts

Flywheels (Low-Speed and High-Speed)
Flywheels store kinetic energy in a rotating mass. The amount of stored energy is dependent on the speed, mass, and configuration of the flywheel. They have been used as short-term energy storage devices for propulsion applications such as engines for large road vehicles. Today, flywheel energy storage systems are usually categorized as either low-speed or high-speed. High-speed wheels are made of high strength, low-density composite materials, making these systems considerably more compact than those employing lower-speed metallic wheels. However, the low-speed systems are still considerably less expensive per kWh.

Supercapacitors
Supercapacitors are also known as Electric Double Layer Capacitors, pseudocapacitors, or ultracapacitors. Charge is stored electrostatically in polarized liquid layers between an ionically conducting electrolyte and a conducting electrode. Though they are electrochemical devices, no chemical reactions occur in the energy-storage mechanism. Since the rate of charge and discharge is determined solely by its physical properties, an ultracapacitor can release energy much faster (i.e., with more power) than a battery, which relies on slow chemical reactions. Ultracapacitors deliver up to 100 times the energy of a conventional capacitor and deliver 10 times the power of ordinary batteries.

Compressed-Air Energy Storage (CAES)
CAES systems store energy by compressing air within a reservoir using off peak/low cost electric energy. During charging, the plant's generator operates in reverse – as a motor – to send air into the reservoir. When the plant discharges, it uses the compressed air to operate the combustion turbine generator. Natural gas is burned during plant discharge in the same fashion as a conventional turbine plant. However, during discharge, the combustion turbine in a CAES plant uses all of its mechanical energy to generate electricity; thus, the system is more efficient. CAES is an attractive energy-storage technology for large-scale storage.

Superconducting Magnetic Energy Storage (SMES)
SMES systems store energy in the magnetic field created by the flow of direct current in a coil of superconducting material. SMES systems provide rapid response to either charge or discharge, and their available energy is independent of their discharge rate. SMES systems have a high cycle life and, as a result, are suitable for applications that require constant, full cycling and a continuous mode of operation. SMES systems are ideal for high-power applications. Micro-SMES devices in the range of 1 to 10 MW are available commercially for power-quality applications.

Representative Technologies

- While the system-concepts section addressed energy-storage components exclusively, all advanced storage systems require power conditioning and balance of plant components.
- For vehicle applications, flywheels, CAES, and ultracapacitors are under development.
- A dozen companies are actively developing flywheels. Steel, low-speed flywheels, are commercially available now; composite, high-speed flywheels are rapidly approaching commercialization.
- Pneumatic storage (CAES) is feasible for energy storage on the order of hundreds of MWh.
- Prototype ultracapacitors have recently become commercially available.

Technology Applications

- A number of industries rely upon high power quality, especially the semiconductor manufacturing and banking industries. Power quality losses total more than $15 billion per year in the U.S.

Energy available in SMES is independent of its discharge rating, which makes it very attractive for high power and short time burst applications such as power quality.

- SMES are also useful in transmission enhancement as they can provide line stability, voltage and frequency regulation, as well as phase angle control.
- Flywheels are primarily used in transportation, defense, and power quality applications.
- Load management is another area where advanced energy-storage systems are used (e.g., CAES). Energy stored during off-peak hours is discharged at peak hours, achieving savings in peak energy, demand charges, and a more uniform load.
- Load management also enables the deferral of equipment upgrades required to meet an expanding load base which typically only overloads equipment for a few hours a day.
- Ultracapacitors are used in consumer electronics, power quality, transportation, and defense and have potential applications in combination with distributed generation equipment for following rapid load changes.

Current Status

- Utilities require high reliability, and per-kilowatt costs less than or equal to those of new power generation ($400–$600/kW). Compressed gas energy storage can cost as little as $1–$5/kWh. SMES has targets of $150/kW and $275/kWh. Batteries cost between $300 and $2,000 per kWh. Vehicles require storage costs of $300 to $1,000/kWh to achieve significant market penetration. The major hurdle for all storage technologies is cost reduction.
- Ultracapacitor development needs improved energy density from the current 1.9 W-h/kg for light-duty hybrid vehicles.

Efficiencies for these technologies are 70% for compressed gas, 70-84% for batteries, and 90+% for flywheels and SMES.

- Low-speed (7,000-9,000 rpm) steel flywheels are commercially available for power quality and UPS applications.
- There is one 110-MW CAES facility operated by an electric co-op in Alabama. One CAES facility is in operation in Germany.
- Nine SMES units have been installed in Wisconsin to stabilize a ring transmission system.

Representative Current Manufacturers

Flywheels	Supercapacitors	CAES	SMES
Active Power American Flywheel Systems Pillar	Nanolab Cooper Maxwell NEC	Ingersoll Rand ABB Dresser-Rand Alstrom	American Superconductor

Technology Future
• Developments in the vehicular systems will most likely crossover into the stationary market. • High-temperature (liquid-nitrogen temperatures) superconductors that are manufacturable and can carry high currents could reduce both capital and operating costs for SMES. • High-speed flywheels need further development of fail-safe designs and/or lightweight containment. Magnetic bearings will reduce parasitic loads and make flywheels attractive for small uninterruptible power supplies and small energy management applications. • Much of the R&D in advanced energy storage is being pursued outside the United States, in Europe, and Japan. U.S. government research funds have been very low, relative to industry investments. One exception has been the Defense Advanced Research Programs Agency, with its flywheel containment development effort with U.S. flywheel manufacturers, funded at $2 million annually. The total DOE Energy Storage Program budget hovers in the $4 million to $6 million range during the past 10 years.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003.

Advanced Energy Storage

Market Data

Market Predictions — Source: Sandia National Laboratories, Cost Analysis of Energy-Storage Systems for Electric Utility Applications, February 1997.

Energy-Storage System	Present Cost	Projected Cost Reduction
SMES	$54,000/MJ	5-10%
Flywheels	$200/kWh	443

Technology Performance

Energy-Storage Costs and Efficiencies — Source: Sandia National Laboratories, Characteristics and Technologies for Long- vs. Short-Term Energy Storage, March 2001.

Energy-Storage System	Energy-Related Cost ($/kWh)	Power Related Cost ($/kW)	Balance of Plant ($/kWh)	Discharge Efficiency
Micro-SMES	72,000	300	10,000	0.95
Mid-SMES	2,000	300	1,500	0.95
SMES	500	300	100	0.95
Flywheels (high-speed)	25,000	350	1,000	0.93
Flywheels (low-speed)	300	280	80	0.9
Ultracapacitors	82,000	300	10,000	0.95
CAES	3	425	50	0.79

Technology Performance

Energy-Storage Technology Profiles

Source: DOE/EPRI, *Renewable Energy Technology Characterizations,* EPRI TR-109496, 1997*,* Appendix A.

Technology	Installed U.S. Total	Facility Size Range	Potential/Actual Applications
Flywheels	1-2 demo facilities, no commercial sites. In 2002, steel flywheels with rotational speeds of 7000-9000 rpm are commercially available for power quality and UPS applications.	kW scale	Electricity (Power Quality) Transportation, Defense
SMES	5 facilities with approx. 30 MW in 5 states	From 1-10 MW (micro-SMES) to 10-100 MW	Electricity (T&D, Power Quality)
Ultracapacitors	Millions of units for standby power; 1 defense unit	7-10 W commercial 10-20 kW prototype	Transportation Defense Consumer Electronics Electricity (Power Quality)
CAES	110 MW in Alabama	25 MW to 350 MW	Electricity (Peak-shaving, Spinning Reserve, T&D)